GYRATORY COMPACTOR APPARATUS AND ASSOCIATED DEVICES AND METHODS

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/439,250, filed January 10, 2003.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a gyratory compactor apparatus and, more particularly, to an improved gyratory compactor apparatus and associated devices and methods.

Description of Related Art

In order to measure certain physical properties, such as density, moisture content and compressive strength, of some materials, such as soil or paving material, loose samples of the soil or paving material are formed into test specimens under reproducible conditions using laboratory compaction machines. It is desirable to compact the test specimens under conditions that simulate actual use. For a paving material sample, this requires simulation of the kneading force applied to the paving material by the paving roller. Simply applying a compressive force to the sample does not adequately simulate the kneading action of the paving roller. As a result, compaction machines that gyrate the sample during compression have been developed to simulate actual conditions of use.

For example, a compaction machine which provides axial compression while gyrating the sample of soil or paving material so as to effectively knead the sample is illustrated in U.S. Patent No. 5,323,655 to Eagan *et al.* The gyratory compactor described therein includes a ram applying compressive force from one end of a

cylindrical mold, wherein the other end of the mold is gyrated by rotating a base supporting the other end of the mold.

Another example of a gyratory compactor apparatus is disclosed in U.S. Patent No. 5,939,642 to King *et al.* The '642 patent describes a gyratory compactor apparatus design for facilitating ergonomics and efficiency, while improving consistency of operating parameters. The gyratory compactor described therein allows the user to slide the cylindrical compaction mold into the compaction chamber without the necessity of lifting the mold and includes an integral specimen removal ram. In addition, the frame design reduces frame deflection that could undesirably affect the angle of gyration. Further, the angle of gyration of the compactor apparatus can be changed by simply replacing a single component of the apparatus.

Notwithstanding the advances that have been made in the art of gyratory compactors, there is a need for smaller and less costly designs, with improved operational efficiency and accuracy. Additionally, there is a need for a gyratory compactor having improved ergonomics. For example, placement and removal of the mold containing the sample should be accomplished with minimal difficulty. Also, it would be advantageous to provide a compactor design that allows the user to quickly and easily change operating parameters, such as the angle of gyration. Further, there is a need in the art for a gyratory compactor that provides a constant angle of gyration during the compaction procedure with minimal deviation therefrom.

BRIEF SUMMARY OF THE INVENTION

The above and other needs are met by the present invention which, in one embodiment, provides a gyratory compactor apparatus adapted to interact with a generally cylindrical mold having an outer diameter, defining an axis, and adapted to have a sample disposed therein. The mold also includes opposed first and second ends and a radially extending flange having an outer diameter. Such a gyratory compactor apparatus comprises a frame defining an axis and a mold-engaging device adapted to receive the mold and to axially move the mold with respect to the frame. An offsetable member is operably engaged with the frame and configured to be capable of engaging the second end of the mold when the mold is axially moved into engagement with the

offsetable member by the mold-engaging device. The mold-engaging device is then configured to release the mold such that the mold is independent thereof. The offsetable member is further configured to be capable of being displaced from the frame axis and concurrently movable in an orbital motion about the frame axis. A portion of the mold away from the second end is maintained at a gyration point along the frame axis and, as the second end of the mold is moved in the orbital motion, the mold is gyrated and capable of being dynamically maintained at a gyration angle related to the displacement of the offsetable member, the gyration point, and the frame axis.

Another advantageous aspect of the present invention comprises a gyratory compactor apparatus adapted to interact with a generally cylindrical mold having an outer diameter, defining an axis, and adapted to have a sample disposed therein. The mold also includes opposed first and second ends and a radially extending flange having an outer diameter. Such a gyratory compactor apparatus includes a frame defining an axis and an offsetable member operably engaged with the frame and configured to be capable of engaging the second end of the mold. The offsetable member is further configured to be capable of being displaced from the frame axis and concurrently movable in an orbital motion about the frame axis. A pressure ram is operably and movably engaged with the frame and configured to be capable of moving along the frame axis. A mold-engaging device is operably engaged with the frame and adapted to receive the mold such that the mold axis corresponds to the frame axis and such that the pressure ram is capable of moving axially within the mold to apply a compaction pressure on the sample within the mold. The pressure ram thereby maintains a portion of the mold at a gyration point along the frame axis. The mold-engaging device is further configured to axially move the second end of the mold into engagement with the offsetable member and to then release the mold such that the mold is independent thereof. A securing device is operably engaged with the offsetable member and is movable therewith, wherein the securing device is configured to reversibly engage the second end of the mold so as to secure the second end of the mold to the offsetable member as the second end of the mold is moved in the orbital motion by the offsetable member. The mold is thereby gyrated and capable of being dynamically maintained at a gyration angle related to the displacement of the offsetable member, the gyration point, and the frame axis.

Still another advantageous aspect of the present invention comprises a gyratory compactor apparatus adapted to interact with a generally cylindrical mold having an outer diameter, defining an axis, and adapted to have a sample disposed therein. The mold also includes opposed first and second ends and a radially extending flange having an outer diameter. Such a gyratory compactor apparatus includes a frame defining an axis and configured to receive the mold. A pressure ram is operably and movably engaged with the frame and configured to be capable of moving along the axis thereof. The pressure ram is further capable of being received by and operably engaging the mold through the first end, and moving within the mold to apply a compaction pressure on the sample within the mold. The pressure ram thereby maintains a portion of the mold at a gyration point along the frame axis. An offsetable member is operably engaged with the frame and is configured to be capable of engaging the second end of the mold. The offsetable member is further configured to be capable of being displaced from the frame axis and concurrently movable in an orbital motion about the frame axis, such that the second end of the mold is moved in the orbital motion. The mold is thereby gyrated and is capable of being dynamically maintained at a gyration angle related to the displacement of the offsetable member, the gyration point, and the frame axis.

Yet another advantageous aspect of the present invention comprises a gyratory compactor apparatus defining an axis. Such an apparatus includes a pressure ram configured to be capable of moving along the apparatus axis and a rotatable member configured to be rotatable about the apparatus axis. A mold is capable of being disposed between the pressure ram and the rotatable member and is adapted to have a sample disposed therein. The mold is generally cylindrical, defines an axis, and has opposed first and second ends. The mold is configured to receive the pressure ram therein through the first end so as to apply a compaction pressure on the sample within the mold, wherein the pressure ram thereby maintains a portion of the mold at the gyration point along the apparatus axis. The second end of the mold defines a radiused bearing surface extending about an inner circumference thereof. An offsetable member is operably engaged with the rotatable member and defines a radiused bearing surface complementarily corresponding to the second end bearing surface of the mold. The offsetable member bearing surface is capable of movably engaging the second end bearing surface of the

mold. The offsetable member is further configured to be displaceable with respect to the rotatable member from the apparatus axis so as to cause the second end of the mold to orbit about the apparatus axis when the offsetable member is rotated by the rotatable member. The mold is thereby gyrated at a gyration angle related to the displacement of the offsetable member, the gyration point, and the apparatus axis.

Yet still another advantageous aspect of the present invention comprises a device adapted to interact with a generally cylindrical mold for a gyratory compactor apparatus defining an axis. The mold has an outer diameter, defines an axis, and is adapted to have a sample disposed therein. The mold also has opposed first and second ends and a radially extending flange having an outer diameter. Such a device includes a movable mounting plate configured to be movable between a first position and a second position along the apparatus axis. A pair of pivoting members is pivotably mounted to the movable mounting plate along parallel pivot axes. A support rail mounted is to each pivoting member. The support rails are laterally separated by less than the outer diameter of the flange with the movable mounting plate in the first position, such that the support rails are capable of supporting the mold by the flange. The pivoting members pivot between the first and second positions such that, with the movable mounting plate in the second position, the support rails are separated by more than the outer diameter of the flange and are thereby incapable of supporting the mold by the flange.

Still another advantageous aspect of the present invention comprises a pressure-measuring device adapted for use with a gyratory compactor apparatus. Such a device includes a pressure-bearing member and an elongate stem member defining an axis. The stem member includes a first end operably engaged with the pressure-bearing member and an opposing second end. An elongate sleeve is configured to extend concentrically over the stem member and in close relation thereto so as to be capable of slidably engaging the stem member over an extended engagement length. The sleeve has a first end extending toward the pressure-bearing member, when the sleeve is engaged with the stem member, and an opposing second end. A load-determining device is in communication with the sleeve such that load-determining device is axially fixed with respect to the sleeve. The load-determining device is further configured to be in

communication with the stem member so as to measure an actual axial load exerted on the pressure-bearing member via the stem member.

Yet another advantageous aspect of the present invention comprises a device adapted to determine and maintain an angle of gyration of a mold engaged with a gyratory compactor apparatus defining an axis. The mold is generally cylindrical, defines an axis, and has opposed first and second ends. The mold is gyratable about the apparatus axis at a gyration point displaced from the second end toward the first end. Such a device includes an offsetable member adapted to be capable of engaging the second end of the mold in displacement from the apparatus axis and to be movable in an orbital motion about the'apparatus axis so as to cause the mold to gyrate with respect to the gyration point, wherein the gyration point remotely disposed with respect to the second end of the mold. A sensor device is configured to dynamically determine an actual angle of gyration of the mold, wherein the actual angle of gyration is related to the displacement of the offsetable member, the gyration point, and the apparatus axis. A controller is operably engaged with the offsetable member so as to be capable of directing adjustment of the displacement of the offsetable member to provide a desired angle of gyration with respect to the gyration point. The controller is in communication with the sensor device and is responsive thereto so as to be capable of dynamically adjusting the displacement of the offsetable member to maintain the actual angle of gyration substantially equal to the desired angle of gyration.

Another advantageous aspect of the present invention comprises a gyratory compactor apparatus defining an axis. Such a gyratory compactor apparatus includes a sample-manipulating device adapted to receive a mold having a sample disposed therein, wherein the sample-manipulating device is configured so as to be capable of gyrating the mold while applying a compaction pressure to the sample. A frame member supports the sample-manipulating device, and has at least one component formed of a laminated sheet material.

Yet another advantageous aspect of the present invention comprises a cleaning device adapted to remove sample residue from a gyratory compactor apparatus defining an axis. The gyratory compactor apparatus is further adapted to have an offsetable member operably engaged with a rotatable member configured to be rotatable about the

axis. The offsetable member is further adapted to be capable of engaging an end of a mold having a gyration point away from the end, and to be capable of being displaced from the axis so as to cause the mold to gyrate with respect to the gyration point when the offsetable member is rotated about the axis by the rotatable member. Such a cleaning device includes a plate having a first face supporting the rotatable member, wherein the plate is configured to be non-rotatable about the axis. The plate has a second face opposing the first face and defines a groove in the first face disposed radially outward of the rotatable member, wherein the groove is configured to collect the sample residue. The plate further defines a channel extending from the groove toward the second face, wherein the channel is configured to facilitate removal of the sample residue from the gyratory compactor. A sweeping member is configured to orbit about the axis in operable engagement with the groove defined by the plate so as to move the sample residue along the groove and to direct the sample residue to the channel for removal.

Another advantageous aspect of the present invention comprises a method of manufacturing a gyratory compactor apparatus, wherein the gyratory compactor apparatus includes a frame having a plurality of components. First, the components are operably engaged with a jig configured to align the components in a desired relationship. The components are then secured together so as to form the frame, wherein the frame defines an axis and has alignment members operably engaged therewith. Thereafter, the frame is removed from the jig. A sample-manipulating device having a plurality of components is then operably engaged with the frame, wherein the sample-manipulating device is adapted to receive a mold capable of receiving a sample therein and is configured so as to be capable of gyrating the mold while applying a compaction pressure to the sample. The components of the sample-manipulating device have alignment members, corresponding to the frame alignment members, operably engaged therewith so as to facilitate alignment of the sample-manipulating device with respect to the axis when the sample-manipulating device is operably engaged with the frame.

Thus, embodiments of the present invention provide significant advantages as detailed further herein.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

Having thus described the invention in general terms, reference will now be made to the accompanying drawings, which are not necessarily drawn to scale, and wherein:

FIG. 1 is a schematic of a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 2 is a schematic of a gyration angle of a mold engaged with a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 3 is a schematic of a mold angle sensing device in communication with a controller for providing a closed-loop control system for a mold engaged with a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 4 is a flow diagram of a gyratory compaction procedure implemented by a closed-loop control system according to one embodiment of the present invention;

FIG. 5 is a schematic of an external mold angle sensing device implementing contact type sensors to determine the gyration angle of a mold for a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 6A is a schematic of an axial-load focusing load cell configuration implemented in conjunction with a mold-securing mechanism to interact with a mold for a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 6B is a schematic of an axial-load focusing load cell configuration implemented to interact with a mold for a gyratory compactor apparatus according to another embodiment of the present invention;

FIG. 7 is a schematic of a cleaning mechanism implemented in conjunction with an offsetable member supported by a rotatable member and configured to interact with a mold for a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 8 is a schematic cutaway view of a gyratory compactor apparatus according to one embodiment of the present invention illustrating a composite construction of the frame of the gyratory compactor apparatus;

FIGS. 9A and 9B are schematics of a mold-handling device configured to manipulate a mold for a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 9C is a schematic of a mold-handling device cooperating with an offsetable member to gyrate a mold with a gyratory compactor apparatus according to one embodiment of the present invention;

FIGS. 10A and 10B are schematics of a mold-handling device configured to manipulate a mold for a gyratory compactor apparatus according to another embodiment of the present invention;

FIGS. 11A-11B are schematics of a mold-handling device configured to manipulate a mold for a gyratory compactor apparatus, the mold-handling device being in an open position, according to yet another embodiment of the present invention;

FIGS. 11C-11D are schematics of a mold-handling device configured to manipulate a mold for a gyratory compactor apparatus, the mold-handling device being in a closed position, according to the embodiment of the present invention shown in **FIGS. 11A-11B**;

FIG. 12A and 12B are schematics of a mold-securing mechanism configured to interact with a mold for a gyratory compactor apparatus according to one embodiment of the present invention;

FIG. 13 is a schematic of a mold-securing mechanism and an anti-rotation device, both configured to interact with a mold for a gyratory compactor apparatus according to one embodiment of the present invention; and

FIG. 14A and 14B are schematics of an external mold angle sensing device implementing contact type sensors to determine the gyration angle of a mold for a gyratory compactor apparatus according to another embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention now will be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the invention are shown. Indeed, this invention may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like numbers refer to like elements throughout.

FIGS. 1-10B illustrate various aspects of a gyratory compactor apparatus according to one embodiment of the present invention, the apparatus being indicated generally by the numeral **10**. Such an apparatus **10** generally comprises a frame **100** defining an axis **150**. The frame **100** is configured to have a pressure ram **200** engaged therewith, wherein the pressure ram **200** is capable of moving along the axis **150**. Opposing the pressure ram **200** is a rotatable member **300** that is also aligned with the axis **150** and is rotatable thereabout. Disposed between the pressure ram **200** and the rotatable member **300** is an offsetable member **400**. In cooperation with the frame **100**, the general area between the pressure ram **200** and the offsetable member **400** defines a mold well **500** configured to accept a mold **600**. The apparatus **10** further includes a mold-handling device **700** configured to receive and manipulate the mold **600** within the mold well **500**. The apparatus **10** also has incorporated therewith a control system **800** configured to interact with the mold **600** when the mold **600** is received in the mold well **500**.

In one advantageous embodiment of the present invention, the frame **100** is comprised of a plurality of components **110** fastened together, for example, by fasteners, by adhesive, by welding, or in any other suitable manner consistent with the spirit and scope of the present invention. As one skilled in the art will appreciate, and as further discussed herein, accurate and precise alignment of the components is critical to the operation of the apparatus **10**, wherein such alignment must be maintained in both static and dynamic states. As such, a variety of stresses are imparted to the frame **100** during the gyratory compaction process, thereby further requiring that some of the frame components **110** be configured to handle different stresses than some other components **110**. In addition, one of the parameters which must also be considered in the design and construction of the apparatus **10** is the weight thereof.

Accordingly, it is advantageous to be able to customize the configuration of, rigidify, and/or reinforce particular frame components **110** where necessary, while minimizing the number of components **110**, in order to optimize the configuration of the frame **100**. Therefore, some advantageous embodiments of the present invention utilize one or more components **110** having a composite construction. For example, **FIG. 8** illustrates a component **110** constructed of individual members, with one or more of those

members comprising two coplanar metal sheets joined together by welding, adhesive, fasteners, or in any other suitable manner. That is, one of those members may be configured such that any wall, side, or otherwise defining surface may be comprised of at least two coplanar sheets secured together. However, the illustrated construction of the component **110** is not intended to be limiting since one skilled in the art will readily appreciate that the composite construction of a component **110** may include more than two sheets and may also include sheets comprised of many different materials, such as metals, polymers, or even other composites. In addition, the composite construction may also be selectively applied such as, for example, where only spot reinforcing is necessary for a component **110**, such that only a portion of a component **110** may include the described composite construction. Further, other measures may also be implemented to prevent the adjacent sheets of the composite from moving with respect to each other where, for example, the adjacent sheets may include interlocking tabs or other mechanical structures (not shown) for minimizing or preventing such relative movement. Thus, embodiments of the present invention utilizing composite construction will realize significant savings in the weight of the frame **100**, whereby the configuration of the frame **100** can be optimized with a minimum of components **100** without sacrificing the strength necessary for withstanding the stresses imparted thereto during operation of the apparatus **10**.

As previously described, accurate and precise alignment of its components is critical to the operation of the apparatus **10** where, as further described herein, such components are discrete with respect to the frame **100** and must be assembled therewith in order to obtain a functional apparatus **10**. Heretofore, assembly of a gyratory compactor apparatus typically required a trained technician, sophisticated alignment tools, and specific procedures for the gyratory compactor to be properly assembled and suitably aligned. Such measures would often need to be duplicated if the gyratory compactor was disassembled for maintenance or to be moved. The disadvantages of those requirements and procedures should be readily apparent to one skilled in the art. Accordingly, other advantageous embodiments of the present invention implement an alignment procedure into the manufacturing process for the frame **100** and, in some instances, other components of the apparatus **10**. More particularly, during the

manufacturing process for the frame **100**, one or more components **110** are engaged with one or more jigs (not shown), each of which is specifically configured to hold and align the components **110** in a specific relationship. The specific relationship typically corresponds to the determination of the frame axis **150**, though other references related to the apparatus **10** may also associated with a particular jig. One or more of the components **110** may also have one or more alignment members (not shown) attached thereto or otherwise associated therewith, or the alignment members may be formed through cooperation between components **110**.

While in the jig, the components **110** may be secured together, for example, by welding, with adhesives, with fasteners, or the like to form the frame **100** or a subassembly thereof. In instances where the entire frame **100** is formed in the jig, the components **110** forming the frame **100** will be properly aligned when the completed frame **100** is removed from the jig. In addition, the alignment members will then serve to align the frame **100** with the other components that are attached to the frame **100** to form the apparatus **10**. Where a subassembly of the frame **100** is formed by the components **110** in the jig, that subassembly will be properly aligned when removed from the jig, while the alignment members will serve to align that subassembly with respect to the frame **100**, or one or more of the other components attached to the frame **100**, to form the apparatus **10**. In some embodiments, the other components attached to the frame **100** to form the apparatus **10** may also have alignment members (not shown) corresponding to and capable of interacting with the alignment members associated with the frame **100**. As such, through the use of the jig and, in some instances, the alignment members, the need for a trained technician and special alignment tools and procedures during the gyratory compactor assembly or reassembly process is minimized or eliminated, while also reducing the time and expense associated with an extensive and complicated assembly or reassembly process.

As shown in **FIGS. 1-3, 5, 6A, and 7**, the frame **100** is configured to receive the pressure ram **200** such that the pressure ram is capable of moving along the axis **150** to provide an axial compressive force with respect to the mold **600** received by the apparatus **10**. Accordingly, the mold **600** which, in one instance, has a cylindrical inner surface, must engage the apparatus **10** such that the pressure ram **200** can extend through

the first end **610** of the mold **600** and exert the necessary axial compressive force along the longitudinal axis **620** of the mold **600**. However, the mold **600** must also be gyrated simultaneously with the application of the axial compressive force in order to achieve and simulate the rolling of the paving roller or other compaction device over a material surface. In order to achieve the necessary gyration of the mold **600**, the second end **630** is typically laterally displaced such that the longitudinal axis **620** is tilted by a particular angle **640** (otherwise referred to herein as the mold angle, the angle of gyration, or the gyration angle) with respect to the axis **150** defined by the travel of the pressure ram **200**, as shown, for example, in **FIG. 2**. As the axial compressive force is applied along the axis **150** by the pressure ram **200**, the laterally displaced second end **630** of the mold **600** is moved in an orbital motion about the axis **150**. Since the mold **600**, away from the second end **630** and toward the first end **610**, is constrained about the axis **150** by the pressure ram **200**, the orbital motion of the second end **630** about the axis **150** thus causes the mold **600** to gyrate within the apparatus **10**. This operational characteristic or the apparatus **10** is otherwise referred to herein as the "gyratory compaction" process for the sample **50**.

According to one advantageous embodiment of the present invention, as shown in **FIGS. 2, 3, and 5-7**, the gyratory compactor apparatus **10** further includes an offsetable member **400** operably engaged with the frame **100**, in generally opposing relation to the pressure ram **200**. The frame **100**, the pressure ram **200**, and the offsetable member **400** thereby cooperate to define the mold well **500** capable of receiving the mold **600** therein. The offsetable member **400** is capable of being laterally displaced from the axis **150** so as to cooperate with the pressure ram **200** and the mold **600** to define the gyration angle **640** about a gyration point **650**. The gyration point **650** generally corresponds to the center point **210** of the end of the pressure ram **200** (described further herein as the foot portion **245**) opposing the offsetable member **400**, or may otherwise be defined as the point of intersection of the longitudinal axis **620** of the mold **600** and the axis **150** of the frame **100**.

In order for the mold **600** to gyrate as required, the offsetable member **400** further includes a bearing member **420** engaged therewith. The bearing member **420** is generally configured as a truncated hemisphere having a flat surface **430** and a circumferential

bearing surface **440** with an arcuate profile. The arcuate profile of the bearing surface **440**, in one instance, may be defined by a radius, though the arcuate profile of the bearing surface **440** may be configured in many different manners as required. Accordingly, the second end **630** of the mold **600** also includes a bearing surface **660** centered about the longitudinal axis **620** and complementarily configured with respect to the bearing surface **440** of the bearing member **420**. When the bearing surfaces **440, 660** are engaged, a ball and socket joint is essentially formed, whereby the second end **630** of the mold **600** is essentially constrained, but allowed to pivot about the gyration center **410** (otherwise referred to herein as the center of gyration of the second end **630** of the mold **600**) of the bearing member **420** as the mold **600** is gyrated, the gyration center **410** therefore being disposed along the longitudinal axis **620** of the mold **600**. The gyration center **410** corresponds to the center point of a sphere overlaid on and corresponding to the truncated hemisphere forming the bearing member **420**. Accordingly, since mold **600** gyrates about the bearing member **420** and since the bearing member **420** also functions to constrain the second end **630** of the mold **600**, the lateral displacement of the gyration center **410** of the bearing member **420** from the frame axis **150** the may readily determined. Thus, both the gyration angle **640** and the gyration point **650** may, in turn, be readily determined in a static mode, as well as in a dynamic mode during operation of the apparatus **10**.

Once laterally displaced from the frame axis **150**, the offsetable member **400** / bearing member **420** must be moved in an orbital motion about the frame axis **150** in order to provide the necessary gyration for the mold **600**. Thus, in one embodiment of the present invention, the offsetable member **400** is engaged with and/or supported by the rotatable member **300**, wherein the rotatable member **300** is configured to be rotatable about the frame axis **150**. The offsetable member **400** is thus configured to be laterally displaceable with respect to the rotatable member **300**. The rotatable member **300** is further engaged with and/or supported by a non-rotatable plate **320**, as shown, for example, in **FIGS. 5 and 7**, wherein the plate **320** may be engaged with or an integral component of the frame **100**. The plate **320** has a first face **330** directed toward the rotatable member **300** and an opposing second face **340**. In one embodiment, the plate **320** may also be configured to define a groove **350** extending through the first face **330**

and disposed radially outward of the rotatable member **300**. In such instances, the groove **350** may further include one or more channels **360** extending from the groove **350** toward the second face **340** of the plate **320**.

Since the offsetable member **400** may interact closely with the sample **50**, residue from the sample **50** may undesirably gather about the offsetable member **400** and the rotatable member **300** in some embodiments, particularly when the offsetable member **400** and the rotatable member **300** are disposed at the lower end of the mold well **500**. Accordingly, in such instances, the groove **350** is provided to collect the sample residue, while the one or more channels **360** is provided to direct the sample residue outwardly of the apparatus **10** from the groove **350**. Also provided is a sweeping member **370** which, in one embodiment, is engaged with the rotatable member **300** so as to be rotatable therewith in engagement with the groove **350**. The sweeping member **370** is further configured to have a profile generally corresponding to the cross-sectional shape of the groove **350** such that, as the sweeping member **370** is drawn around the groove **350** by the rotating rotatable member **300**, sample residue in the groove **350** is directed into the one or more channels **360** and thus outwardly of the apparatus **10**. In some embodiments, the sweeping member **370** is also configured so as not to interfere with the offsetable member **400** as the offsetable member **400** is laterally displaced with respect to the rotatable member **300**. Accordingly, the sweeping member **370** is capable of cooperating with the groove **350** and the one or more channels **360** to remove sample residue from the mold well **500** as the apparatus **10** is operated, thereby reducing or eliminating the need to manually remove sample residue from the mold well **500** when the apparatus **10** is idle.

As previously discussed, one of the purposes of a gyratory compactor apparatus **10** is to impart an axial compressive force on the sample **50** as the sample **50** is being gyrated. The necessary axial compressive force is thus provided by the pressure ram **200**, as shown in **FIG. 6A**, that is engaged with the frame **100** and configured to provide the compressive force along the axis **150**. It is also typically desirable for the value of the axial compressive force to be accurately measured and such a measurement is generally accomplished through the use of a load cell. However, a load cell may indicate an inaccurate value if subjected to an eccentric or non-axial applied load where, in a

gyratory compactor, such eccentric forces may be generated as the mold is gyrated. Accordingly, one advantageous aspect of the present invention comprises a load cell **210** engaged between the ram tube **220** and the ram head **230** of the pressure ram **200**, whereby the ram tube **220** is configured to receive, with close tolerance, a cylindrical portion **240** of the ram head **230** therein such that the ram tube **220** interacts with the cylindrical portion **240** over an extended length. A first end **250** of the cylindrical portion **240** extends into the ram tube **220**, while a second end **260** is directed outwardly thereof.

The load cell **210** is disposed within the ram tube **220** so as to interact with the first end **250** of the cylindrical portion **240**. Though the load cell **210** is shown to directly interact with the first end **250**, indirect interaction such as, for example, in instances where a spacer (not shown) is disposed therebetween, is also suitable. The load cell **210** is preferably disposed as close to the first end **250** as possible. In addition, the load cell **210** is preferably securely constrained from movement along the axis of the ram tube **220** away from the ram head **230**. For example, the ram tube **220** may include a mounting member **270** constrained from axial movement along the ram tube **220** away from the ram head **230** by a change in diameter of the ram tube **220**, or by any other suitable mechanism. The load cell **210** is secured to the mounting member **270** and is thus firmly secured within the ram tube **220**. Pressure exerted on the sample **50** by the ram head **230** is thereby transmitted by the cylindrical portion **240** to the load cell **210** which, as will be readily appreciated by one skilled in the art, allows the pressure applied to the sample **50** to be determined. However, the extended interaction length and the close tolerance between the ram tube **220** and the cylindrical portion **240** of the ram head **230**, according to advantageous aspects of the present invention, serves to dissipate any eccentric forces transmitted to the ram head **230** through the ram tube **220**, during gyration of the mold **600**. Accordingly, any eccentric forces acting on the ram head **230** will not be transmitted to the load cell **210**.

The load cell **210** thereby experiences only a focused axial load from the ram head **230**, and the load cell **210** configured according to embodiments of the present invention will thus more accurately indicate the axial compressive force exerted on the sample **50** by the pressure ram **200** during the gyratory compaction process. One skilled in the art will also appreciate that the axial compressive force applied on the sample **50**

may also be determined in other ways such as described, for example, in U.S. Patent Application No. 10/210,020, also assigned to the assignee of the present invention, entitled "*Method and Apparatus for Determining the Angle of Gyration and/or the Pressure in a Gyratory Compactor*" and filed on July 31, 2002, which is incorporated herein by reference.

One skilled in the art will also appreciate that the pressure ram **200**, as shown in **FIG. 6A**, may have different operating mechanisms for applying the desired compaction pressure. Further, the load cell **210** may be remotely displaced with respect to the ram head **230**. For example, the configuration previously described may include a hydraulic system (not shown) for forcing the ram head **230** out of the ram tube **220** to provide the compaction pressure. **FIG. 6B** illustrates another example of a mechanism for applying compaction pressure via the pressure ram **200**. As shown, the ram tube **220** may be configured to receive a ram shaft **225** therein through the proximal end **220b** thereof, wherein the ram shaft **225** includes opposing ends **225a, 225b**. The end **225b** of the ram shaft **225** disposed outwardly of the ram tube **220** is configured to receive the cylindrical portion **240** of the ram head **230**. The opposing end **225a** of the ram shaft **225** includes internal threads (the end of the ram shaft **225** may be threaded or the ram shaft **225** may include a nut member operably engaged therewith) and is configured to receive a screw portion **235a** of a screw drive mechanism **235** engaged with the distal end **220a** of the ram tube **220**. Note, however, that the screw drive mechanism **235** may be engaged with the ram tube **220** and ram shaft **225** in many different manners than the embodiment described herein. The load cell **210**, in this instance, is remotely disposed with respect to the ram head **230** and is engaged with the drive portion **235b** of the screw drive mechanism **235** such that the axial pressure generated by the screw drive mechanism **235** against the ram shaft **225**, and thus the ram head **230**, is measured. Accordingly, as before, an extended interaction length and close tolerance between the ram tube **220** and the ram shaft **225** serves to dissipate any eccentric forces transmitted to the load cell **210** via the drive portion **235b** of the screw drive mechanism **235** during gyration of the mold **600**. Accordingly, any eccentric forces acting on the ram head **230** will not be transmitted to the load cell **210**, and the load cell **210** will experience only a focused axial load from the ram head **230**. The load cell **210** will thus more accurately indicate the

axial compressive force exerted on the sample **50** by the pressure ram **200** during the gyratory compaction process.

As shown in **FIG. 2**, the apparatus **10** further includes a first puck **670** capable of being disposed within the mold **600** toward the second end **630** thereof. The mold **600** and/or the first puck **670** are configured such that the first puck **670** is temporarily retained toward the second end **630** so as to cooperate with the mold **600** to contain the sample **50**. For example, the first puck **670** may be temporarily retained in place within the mold **600** by a ring **615** engaged with the inner surface of the mold **600** so as to retain the sample **50** in the mold **600** as the mold **600** is inserted into or removed from the mold well **500**. Upon application of the compressive force by the pressure ram **200**, the first puck **670** moves along the mold **600** and into contact with the flat surface **430** of the bearing member **420**. The ram head **230** of the pressure ram **200** also includes a foot portion **245** attached to the second end **260** of the cylindrical portion **240** or ram shaft **225** outwardly of the ram tube **220**. In some instances, the foot portion **245** functions as a "puck" and opposes the first puck **670** within the mold **600**, whereby the sample **50** is disposed therebetween and inside the mold **600**. In other instances, a second puck **680** (shown in phantom) may be disposed within the mold **600** between the foot portion **245** of the pressure ram **200** and the sample **50** such that the foot portion **245** does not directly interact with the sample **50**. However, as previously discussed, the center point **210** of the foot portion **245** defines the gyration point **650** of the mold **600** and the foot portion **245** moves closer to the bearing member **420** as the sample **50** is compacted during the gyratory compaction process. Accordingly, the foot portion **245** may be described as "inactive" since the first end **610** of the mold **600** is not constrained to provide a fixed gyration point **650** and since the foot portion **245** is not capable of laterally translating in order to maintain the gyration angle **640** as the sample **50** is compacted. As such, the gyration angle **640**, which is typically required remain constant at a specified value during the compaction process, will change as the sample **50** is compacted.

As a result, advantageous embodiments of the present invention also implement a closed loop control system **800**, as shown, for example, in **FIGS. 3 and 4**, for continuously monitoring the gyration angle **640** and dynamically adjusting the lateral displacement of the offsetable member **400** during the gyratory compaction process so as

to maintain the specified value of the gyration angle **640** as the sample **50** is compacted. More particularly, the control system **800** comprises a controller **810** and a mold angle sensing device **820**. The mold angle sensing device **820**, as shown in **FIG. 5**, includes a pair of sensors **830** aligned with and separated by a distance along the frame axis **150**. The sensors **830** are configured to interact with the exterior surface of the mold **600** and may be, for example, contact sensors, proximity sensors, or any other suitable contacting or non-contacting sensors or combinations thereof, wherein one skilled in the art will readily appreciate that the gyration angle **640** of the mold **600** may be determined from the difference in the absolute distances between each of the sensors **830** and the exterior surface of the mold **600**. However, in some instances, the gyration angle **640** may be determined from inside the mold **600** using, for example, a device for determining the angle of the mold as also disclosed in U.S. Patent Application No. 10/210,020, previously incorporated herein by reference. One skilled in the art will also appreciate that the gyration angle **640** may also be determined in other manners such as, for example, longitudinally along the mold **600**.

The sensors **830** are in communication with the controller **810**, wherein the controller **810** is configured to direct the displacement of the pressure ram **200**, and thus the foot portion **245**, into the mold **600** so as to establish the specified axial compression force on the sample **50** as measured, for example, by the load cell **210**. The controller **810** is also configured to read the displacement or proximity values indicated by the sensors **830** and to determine the actual mold angle **640**. The controller **810** is further capable of comparing the actual mold angle **640** to the specified or desired mold angle and then directing the adjustment of the lateral displacement of the offsetable member **400** until the desired mold angle is attained. The controller **810**, in some instances, is configured to simultaneously measure, and adjust if necessary, both the compression force on the sample **50** and the mold angle **640**. In other instances, the measurements and any necessary adjustments may be performed at spaced intervals or may be performed with such frequency that the compaction force and mold angle **640** are maintained in approximately real time. One skilled in the art will also readily appreciate that the controller **810** may take many different forms depending at least partially on the complexity of the required parameter control for the apparatus **10** as well as the degree of

automation or user friendliness desired by the end user. Further, though the determination of the gyration angle **640** is described herein in terms of a lateral displacement of the offsetable member **400**, it will be understood that the control of the position of the offsetable member **400** may be accomplished in different manners such as, for instance, according to a Cartesian coordinate system and using, for example, an x-y table. In some embodiments of the present invention, a polar coordinate system is implemented via a polar excursion table which uses two parallel and concentric plates (the offsetable member **400** and the rotatable member **300**), whereby the offsetable member **400** is translated according to the polar coordinate system into an eccentric position with respect to the rotatable member **300**, as both are rotated about the axis **150**. However, the example presented herein are not intended to be limiting since many other configurations of the apparatus **10** may be provided that are capable of providing the necessary lateral displacement of the second end **630** of the mold **600** as well imparting the required orbital motion of the second end **630** about the axis **150** in order to produce the gyration of the mold **600**.

The ergonomics of the apparatus **10** are also considered in embodiments of the present invention. For example, the mold **600** having the puck **670** and sample **50** disposed therein may be heavy and cumbersome. Thus, it would be advantageous to minimize the handling necessary to load the mold **600** into the mold well **500** and to align the mold **600** with the bearing member **420** and the pressure ram **200**. According to advantageous embodiments of the present invention, the apparatus **10** is further provided with a mold-handling device **700**, as shown, for example, in **FIGS. 9A-9C**, for receiving and handling the mold **600** within the mold well **500**. Initially, the mold **600** must be inserted into the mold well **500** and the second end **630** then lowered into engagement with the bearing member **420**. As such, the frame **100** further includes a staging member **160** configured to receive the mold **600** thereon on a level such that the second end **630** is above the level of the flat surface **430** of the bearing member **420**. Each end **610, 630** of the generally cylindrical mold **600** may also include a flange **690a, 690b** (the mold **600** may include either or both of the flanges **690a, 690b**, as appropriate for any embodiment of the invention as disclosed herein) extending radially outward therefrom to an outer diameter greater than the outer diameter of the mold **600**. In one embodiment, the flange

690a at the first end **610** of the mold **600** includes a pair of flat portions **695a** formed therein such that the flat portions **695a** are separated by a distance less than the outer diameter of the flange **690a** and such that each of the flat portions **695a** are separated from the first end **610** of the mold **600** by a lip portion **695b** of the flange **690a**.

As shown in **FIG. 9B**, a receiving fork **705**, generally comprising a pair of spaced apart tines **710** attached to a transversely-extending support member **715**, is disposed toward the pressure ram end of the mold well **500**, as shown in **FIGS. 9A and 9C**. In one embodiment, the receiving fork **705** is operably engaged with the frame **100** and is axially movable in cooperation with the pressure ram **200** along the frame axis **150**, as discussed further below. The fork **705** is configured such that, when the mold **600** is placed on the staging member **160** and slid toward the mold well **500**, the first end **610** of the mold **600** clears the foot portion **245** of the pressure ram **200** and the flat portions **695a** of the flange **690a** are received between the tines **710**. Accordingly, the tines **710** and the flat portions **695a** cooperate to ensure that the mold **600** is received in the mold well **500** is a desired rotational orientation. The support member **715** may be further configured to cooperate with the tines **710** so as to properly align the mold **600** within the mold well **500**, such that the mold axis **620** is coaxial with the frame axis **150**, when the mold **600** is received within the fork **705**. The proper alignment may be ensured in many different manners such as, for example, through the mechanical configuration of the fork **705** or via an appropriate sensor (not shown) configured to sense when the mold **600** is received in the desired position. When the mold **600** is properly inserted into the fork **705**, the mold **600** is no longer supported by the staging member **160**, but instead is suspended above the bearing member **420** and supported by the lip portions **695b** of the flange **690a** on the tines **710** of the fork **705**.

Once the mold **600** is inserted into the fork **705**, the pressure ram **200** can be directed by the controller **810** to move toward the bearing member **420**. As a result, the fork **705** will also move toward the bearing member **420**, thereby lowering the second end **630** of the mold **600** into engagement with the bearing member **420**. The fork **705** also moves axially along the mold **600**, away from the flat portions **695a** and the lip portions **695b** of the flange **690a**, when the mold **600** is sufficiently lowered so as to be supported by the bearing member **420**. Further advancement of the pressure ram **200**

causes the foot portion **245** to enter the first end **610** of the mold **600**, and still further advancement of the pressure ram **200** is capable of providing the necessary axial compressive force on the sample **50**, whereafter the gyration angle **640** may then be subsequently established.

In some instances, the mold-handling device **700** may further include a securing device **720** engaged with the fork **705** and configured to maintain the second end **630** of the mold **600** in sufficient contact with the bearing member **420** during the gyratory compaction process. The securing device **720** and the first end **610** of the mold **600** are configured similarly to the bearing member **420** / second end **630** configuration previously discussed. That is, the securing device **720** is generally configured as a truncated hemisphere having an inner end **725** and a circumferential bearing surface **730** having an arcuate profile. Accordingly, the first end **610** of the mold **600** also includes a bearing surface **665** centered about the longitudinal axis **620** and complementarily configured with respect to the bearing surface **730** of the securing device **720**. When the bearing surfaces **665, 730** are engaged, a ball and socket joint is essentially formed, whereby the first end **610** of the mold **600** is capable of pivoting about the securing device **720** as the mold **600** is gyrated. However, the first end **610** of the mold **600** is also required to allow the foot portion **245** of the pressure ram **200** to enter the mold **600** to provide the compressive force on the sample **50**. Accordingly, the securing device **720** further defines a bore **735** generally corresponding to the cylindrical portion **240** or ram shaft **225** of the ram head **230**, wherein the bore **735** is configured to allow the cylindrical portion **240** or ram shaft **225** to move freely therethrough. The securing device **720** further defines a recess **740** extending from the inner end **725** and disposed in series with the bore **735**. The recess **740** is configured to correspond to the foot portion **245** of the ram head **230** such that, when the ram head **230** is retracted from the mold **600**, the foot portion **245** enters the recess **740** and lies flush with the inner end **725** so as to form a flat surface in connection with the inner end **725**.

As previously discussed, the securing device **720** is configured to maintain the second end **630** of the mold **600** in sufficient contact with the bearing member **420** during the gyratory compaction process. Accordingly, the apparatus **10** may further include one or more biasing devices **900**, such as, for example, a spring type device or other suitable

device, operably engaged between the frame **100** and the securing device **720** for resiliently biasing the securing device **720** into engagement with the first end **610** of the mold **600**, and thus urging the mold **600** against the bearing member **420**. By maintaining the mold **600** in the proper position with respect to the bearing member **420**, the gyration angle **640** can thus be better maintained during the gyratory compaction process. As implemented in embodiments of the present invention, for example, the frame **100** may include one or more mounts **180** adjacent to the pressure ram **200**, whereby the one or biasing devices **900** are disposed between the one or more mounts **180** and the securing device **720**. In some embodiments of the present invention, the fork **705** is engaged with the securing device **720**, wherein both are biased toward the bearing member **420** by the one or more biasing devices **900**. Accordingly, when the foot portion **245** of the pressure ram **200** is fully retracted, the securing device **720** and the fork **705** are drawn back against the one or more biasing devices **900** until the fork **705** is in the proper position to accept the mold **600** from the staging member **160** or for the mold **600** to be removed from the fork **705** onto the staging member **160**. As such, when the mold **600** is inserted into the fork **705**, the foot portion **245** can be moved into the first end **610** of the mold **600**. The one or more biasing devices **900** then urge the securing device **720** / fork **705** assembly toward the bearing member **420**, whereby the moving fork **705** moves the mold **600** into engagement with the bearing member **420**. Further movement of the foot portion **245**, after the mold **600** is engaged with the bearing member **420**, moves the fork **705** out of engagement with the flat portions **695a** and the lip portions **695b** of the flange **690a**, while the one or more biasing devices **900** urges the securing member **720** into engagement with the first end **610** of the mold **600**, whereafter the first end **610** of the mold **600** is supported by the securing device **720**, but not the fork **705**.

However, when the fork **705** is disengaged from the flat portions **695a**, the mold **600** may be able to rotate during the gyratory compaction process, which is not always desirable. Accordingly, in the embodiment as shown in **FIG. 6A**, the securing device **720**, which is typically constrained from rotational movement by the one or more biasing devices **900** or by other arrangements, may define, for example, a recess or receptacle **770** in the bearing surface **730** thereof. A position on the bearing surface **665** or the flange **690a** of the mold **600** may correspondingly include a pin member **780** capable of

extending into the receptacle **770** when the securing member **720** is engaged with the mold **600**, whereby interaction of the pin member **780** and the receptacle **770** prevents the mold **600** from rotating, but still allows the bearing surfaces **665, 730** to interact so as to permit the mold **600** to pivot as necessary with respect to the securing member **720**. One skilled in art will readily appreciate, however, that many different mechanisms may be implemented for preventing the mold **600** from rotating about the axis **150** when not supported by the fork **705** and the configuration described herein is not intended to be limiting in this respect. For example, the pin member **780** may be engaged with the securing device **720** while the receptacle is defined by the mold **600**.

Further, since embodiments of the present invention, as previously described, include a gyration point **650** that moves according to the displacement of the pressure ram **200**, the first end **610** of the mold **600** cannot be constrained from lateral movement if the required gyration angle **640** is to be achieved and maintained during the gyratory compaction process. Accordingly, as shown in **FIG. 9A**, the apparatus **10** may further include a lateral translation device **920** disposed between the securing member **720** and the one or more biasing devices **900** to thereby allow the securing device **720** to bias the mold **600** against the bearing member **420** while permitting the first end **610** of the mold **600** to freely laterally translate as needed. For example, the securing device **720** may be attached to a first translation plate **925** via one or more first sliding mechanisms **930** disposed therebetween, and the first translation plate **925** then attached to a second translation plate **935** via one or more second sliding mechanisms **940** disposed therebetween, wherein the second translation plate **935** is attached to the one or more biasing members **900**. In some instances, the first sliding mechanism(s) **930** are disposed perpendicularly with respect to the second sliding mechanism(s) **940** to allow the securing member **720** to freely laterally translate with respect to the one or more biasing members **900**. However, one skilled in the art will also appreciate that the free lateral translation of the securing member **720** may be accomplished in many different manners and that the configuration disclosed herein is not intended to be limiting in this respect.

One skilled in the art will further appreciate that some components forming the apparatus **10** may be configured in different manners, or to cooperate with other components in different manners, to obtain the same or similar function and results as

described herein. For example, in some embodiments of the present invention, as shown in **FIGS. 10A and 10B**, the fork **705** may be operably engaged with the pressure ram **200** instead of the securing device **720**, or otherwise operated independently of both the pressure ram **200** and the securing device **720**, such that the fork **705** moves independently of the securing device **720**. In some instances, the fork **705** may be configured to move in correspondence with the foot portion **245** of the ram head **230**. In such a configuration, the fork **705** may be disposed in the apparatus **10** to receive the mold **600** or to allow the mold **600** to be removed therefrom as previously described. However, for example, the flange **690a** about the first end **610** of the mold **600** may be configured without the flat portions **695a**, whereby the flange **690a** itself supports the mold **600** when the mold **600** is received by the fork **705**. In order to insure the proper rotational orientation of the mold **600** when inserted into the mold well **500**, the mold **600** may, for instance, define an axially-extending groove **950** in the outer surface thereof, wherein the support member **715** or other component of the fork **705** may have a pin member **955** engaged therewith and extending therefrom so as to be capable of engaging the groove **950** when the mold **600** is received by the fork **705**. In such instances, the pin member **955** is further configured with respect to the groove **950** so that proper engagement therebetween, to prevent the mold **600** from rotating about the axis **150**, is maintained during the gyratory compaction process for a range of axial positions of the fork **705** along the mold **600** or for a range of gyration angles **640** of the mold **600**. For example, the pin member **955** may be configured such that the axial position thereof in engagement with the groove **950** along the mold **600** corresponds to the axial position of the center point **210** of the foot portion **245** of the ram head **230** (the gyration point **650**) within the mold **600** during the gyratory compaction process.

Still further, as shown in **FIG. 10A**, the mold angle sensing device **820** may also be incorporated into the support member **715** or other component of the fork **705** such that the sensors **830** are separated by a distance along and oriented parallel to the axis **150** and operate in a manner as previously described to determine the gyration angle **640**. The sensors **830** may be contact or non-contacting type sensors or any other type of sensor suitable for accomplishing the described functions thereof. In some instances, the sensors **830** may be configured to determine when the mold **600** is within a specified

proximity thereto before providing appropriate signals to the controller **810**, the controller **810** subsequently allowing the apparatus **10** to be operated in response to the signals. In such instances, the mold angle sensing device **820** functions, for example, to indicate that the mold **600** is properly inserted and aligned in the mold well **500** or as a safety interlock for the apparatus **10**.

FIGS. 11A-11D illustrate an alternate embodiment of a mold-handling device **700** for receiving and handling the mold **600** within the mold well **500**. The mold-handling device **700**, in this embodiment, includes a first mounting plate **1100** defining a hole **1110** through which the cylindrical portion **240** or ram shaft **225** of the pressure ram **200** extends. The first mounting plate **1100** is attached to the frame **100** so as to be disposed opposite the ram head **230** from the mold well **500**. A second mounting plate **1200** also defines a hole **1210** through which the cylindrical portion **240** or ram shaft **225** of the pressure ram **200** extends, wherein the second mounting plate **1200** is disposed between the first mounting plate **1100** and the ram head **230**. The second mounting plate **1200** is engaged with the first mounting plate **1100** by one or more biasing devices **1250** (wherein four such biasing devices **1250** are shown in this embodiment) configured to bias the second mounting plate **1200** away from the first mounting plate **1100**.

A pair of pivoting members **1300** are pivotably engaged with the second mounting plate **1200**, on either side of the hole **1210**, wherein the pivoting members **1300** are configured to have parallel pivot axes **1310**. Each pivoting member **1300** is disposed opposite the second mounting plate **1200** from the first mounting plate **1100** and is configured to have a medial pivot such that a portion of the pivoting member **1300** extends inwardly toward the hole **1250**, while the opposing portion extends outwardly of the second mounting plate **1200**. Each pivoting member **1300** further includes a pivot element **1350** engaged therewith and extending to the first mounting plate **1100** or the frame **100**, with each pivot element **1350** being configured to pivot the respective pivoting member **1300** and/or limit the extent to which the respective pivoting member **1300** is capable of pivoting.

One skilled in the art will appreciate that, as described and shown, the second mounting plate **1200** is movable with respect to the frame **100** / first mounting plate **1100**, and the pivoting members **1300** are pivotable with respect to the second mounting plate

1200. Accordingly, as the second mounting plate **1200** is biased away from the first mounting plate **1100** by the biasing devices **1250**, the second mounting plate **1200** and/or pivot elements **1350** restrain the pivoting members **1300** with respect to the first mounting plate **1100**, thus causing the outwardly-extending portions of the pivoting members **1300** to pivot toward the first mounting plate **1100** about the pivot axes **1310**. The pivot elements **1350** also serve to limit pivoting of the pivot members **1300** and movement of the second mounting plate **1200** away from the first mounting plate **1100**. Further, since the cylindrical portion **240** or ram shaft **225** of the pressure ram **200** extends through both of the mounting plates **1100, 1200**, the ram head **230** is capable of pivoting the pivoting members **1300** in the opposite direction. That is, when the ram head **230** is brought to the fully retracted position, away from the bearing member **420**, the ram head **230** will bear on the inwardly-extending portion of the pivoting members **1300**, thereby pivoting the pivoting members **1300** about the pivot axes **1310** in the reverse direction. At the same time, the ram head **230** moves the second mounting plate **1200** toward the first mounting plate **1100**.

The pivoting elements **1300** each include a rail **1000** spaced apart therefrom, away from the second mounting plate **1200**. Each rail **1000** includes an inwardly-extending support ledge **1010**. When the ram head **230** is in the fully retracted position, the rails **1000** are sufficiently spaced apart so as to be capable of accepting the flange **690a** at the first end **610** of the mold **600** therebetween, as shown in **FIGS. 11A and 11B**. The support ledges **1010** are spaced apart by more than the outer diameter of the mold **600**, but less than the outer diameter of the flange **690a**. When the ram head **230** is in the fully retracted position, the support ledges **1010** are at a sufficient height above the staging member **160** such that, when the mold **600** is urged into the mold well **500**, the support ledges **1010** of the rails **1000** receive the mold **600** and support the mold **600**, via the flange **690a**, so that the second end **630** is above the level of the flat surface **430** of the bearing member **420**. A mold stop (not shown) is engaged with the frame **100** and/or the mold-handling device **700** so as to stop the advance of the mold **600** into the mold well **500** from the staging member **160** when the longitudinal axis **620** of the mold **600** is aligned with the frame axis **150**. Once the mold **600** is then inserted into the mold well

500 and supported by the rails 1000, the pressure ram 200 can be actuated to begin the compaction process.

Upon actuation, the ram head 230 is directed into the first end 610 of the mold 600. As the ram head 230 moves into the mold 600, the biasing devices 1250 move the second mounting plate 1200 away from the first mounting plate 1100, thereby lowering the second end 630 of the mold 600 into engagement with the bearing member 420. Continued movement of the ram head 230 into the mold 600 allows the pivot elements 1350 to act upon the pivoting members 1300, thereby causing the pivoting members 1300, and thus the support ledges 1010 to pivot away from the flange 690a of the mold 600, as shown in **FIGS. 11C and 11D**. The mold-handling device 700 is further configured such that, when the support ledges 1010 pivot away from the flange 690a, the second end 630 of the mold 600 is already supported by the bearing member 420. Accordingly, certain embodiments of the present invention provide a substantially seamless transition between the mold 600 being lowered into engagement with the bearing member 420 and the mold-handling device 700 releasing the mold 600 as the pressure ram 200 begins the compaction process. At that point, further advancement of the pressure ram 200 causes the foot portion 245 in the mold 600 to provide the necessary axial compressive force on the sample 50 and establishment of the gyration angle 640.

Since the mold 600 is released by the mold-handling device 700 when the mold 600 is engaged with the bearing member 420 and the pressure ram 200 is beginning the compaction process, the mold 600 must be held in position with respect to the bearing member 420 so as to be substantially prevented from rotating about the longitudinal axis 620. Accordingly, in some embodiments using a mold-handling device 700 as discussed in connection with **FIGS. 11A-11D**, and as shown in **FIG. 13**, the mold 600 includes a medial flange 750 disposed between the first and second ends 610, 630. The medial flange 750 further defines a gap 755 extending circumferentially along the outer surface of the mold 600. An anti-rotation member 760 is engaged or otherwise in communication with the frame 100 and is configured to interact with the gap 755 in the medial flange 750. The anti-rotation member 760, in one embodiment, is disposed in the mold well 500 and normally biased outwardly of the mold well 500 toward the staging member 160 by a biasing device 765. When the mold 600 is inserted into the mold well

500 from the staging member **160**, the anti-rotation member **760** engages the medial flange **750**, and the mold **600** is rotated until the anti-rotation member **760** engages the gap **755**. At the same time, the mold **600** is being received by the mold-handling device **700** and, as such, the anti-rotation member **760** may also serve to provide proper alignment of the mold **600** within the mold-handling device **700** and/or as the mold stop for indicating that the mold **600** is properly inserted into the mold-handling device **700** such that the longitudinal axis **620** is aligned with the frame axis **150**. Accordingly, once the mold **600** is received by the mold-handling device **700** and supported by the rails **1000**, the biasing device **765** maintains the anti-rotation member **760** in engagement with the gap **755** so as to substantially prevent the mold **600** from rotating during the compaction process.

In holding the mold **600** in position with respect to the bearing member **420**, consideration must also be given to preventing the mold **600** from lifting off the bearing member **420**. That is, the mold **600** must be held down or otherwise maintained in proper contact with the bearing member **420** during the compaction process. Accordingly, in some embodiments using a mold-handling device **700** as discussed in connection with **FIGS. 11A-11D**, and as shown in **FIGS. 12A and 12B**, some embodiments of the present invention may further include a hold-down device **850** for securing the mold **600** to the bearing member **420** at the second end **630**. By the hold-down device **850** maintaining the mold **600** in the proper position with respect to the bearing member **420**, the gyration angle **640** can be better maintained during the gyratory compaction process. As the mold **600** is gyrated during the compaction process, the second end **630** of the mold **600** orbits around the frame axis **150**. Accordingly, at any position in the orbit, the flange **690b** at the second end **630** of the mold **600** will have two diametrically-opposed locations **860a, 860b** at the same vertical level with respect to the bearing member **420**. That is, at any instant during the orbit, a plane aligned along the longitudinal axis **620** of the mold **600** and extending tangentially to the gyration center **410** of the bearing member **420** will intersect the flange **690b** at the second end **630** of the mold **600** at two points. The intersection points of the plane with the flange **690b** thus define the same longitudinal locations **860a, 860b** diametrically-opposed about the flange **690b**. However, one skilled in the art will appreciate that, since the mold **600** is substantially

prevented from rotating about the longitudinal axis **620** as the mold **600** is gyrated, the same longitudinal locations **860a, 860b** move around the flange **690b** in the same rotational direction imparted to the offsetable member **400** as it orbits around the frame axis **150**.

As such, in one embodiment, the hold-down device **850** comprises a pair of roller members **855** mounted so as to be diametrically opposed with respect to the bearing member **420**. The roller members **855** are mounted to respective mounting blocks **870**, with each mounting block **870** being rotatable about a respective longitudinally-extending pin member **875** engaged with the offsetable member **400**. The roller members **855** are mounted to the respective mounting block **870** via a laterally-extending axle **880**. The mounting blocks **870** are thus configured to be pivotable so that the roller members **855** can be moved from a first position, as shown in **FIG. 12A**, in which the roller members **855** are disposed over the flange **690b** to a second position, as shown in **FIG. 12B**, in which the roller members **855** and the mounting blocks **870** are disposed radially outward of the flange **690b**. In the first position, the axles **880** are disposed along a line extending through the gyration center **410** such that the roller members **855** are oriented tangentially to the outer surface of the mold **600**. In the second position, the mounting blocks **870** and the rollers members **855** are disposed such that the mold **600** can be lifted from the bearing member **420** without interference.

The mounting blocks **870** are connected by respective arms **885a, 885b** to a position-controlling member **890a** mounted so as to be rotatable about a longitudinally-extending pin member **890b** engaged with the offsetable member **400**. In one embodiment, the position-controlling member **890a** and/or the mounting blocks **870** may be biased to a normal rotational position such as, for example, where the roller members **855** are disposed so as to engage the flange **690b**, or where the roller members **855** are disposed radially outward of the flange **690b**. In some instances, the position-controlling member **890a** and/or the mounting blocks **870** may be biased to both opposing normal positions, wherein the transition between those positions are determined by a cam or other mechanism or device for allowing such biasing on either side of a transition point. The arms **885a, 885b** are engaged between the position-controlling member **890a** and the respective mounting blocks **870** such that, as the position-controlling member **890a** is

rotated in one direction, the roller members **855** are moved into engagement with the flange **690b**, while the roller members **855** are moved away from the flange **690b** when the position-controlling member **890a** is rotated in the opposite direction.

One skilled in the art will appreciate that, before the compaction process can begin, the mold **600** must be moved into engagement with the bearing member **420** and secured thereto by the roller members **855**. At the same time, the mold **600** is prevented from rotating about the longitudinal axis **620** by the anti-rotation member **760**. The position-controlling member **890a** and the mounting blocks **870** are secured to the offsetable member **400**, which does not rotate about the gyratory center **410**. Accordingly, as the mold **600** is gyrated, the position-controlling member **890a** and the mounting blocks **870** move in the orbit with the offsetable member **400**, and the roller members **855** thereby roll around the flange **690b** of the mold **600**, in correspondence with the same vertical level locations **860a, 860b**, while securing the mold **600** to the bearing member **420**.

In some instances, the apparatus **10** may also include a ratcheting member **895** engaged with the frame **100** and capable of engaging the position-controlling member **890a**. That is, the ratcheting member **895** may be mounted such that, as the offsetable member **400** is moved in the orbit by the rotatable member **300** in a normal rotation direction, the ratcheting member **895** initially contacts the position-controlling member **890a** and rotates the position-controlling member **890a** into the position in which the roller members **855** engage the flange **690b** to secure the mold **600** to the bearing member **420**. The ratcheting member **895** may be resiliently biased toward a contact position with the position-controlling member **890a**, or may otherwise be selectively actuatable to the contact position. Upon completion of the compaction process, the roller members **855** must be disengaged from the flange **690b** in order for the mold **600** to be removed from the apparatus **10**. As such, in one embodiment, the rotatable member **300** may be capable of being directed in reverse with respect to the normal rotation direction. In such an instance, the ratcheting member **895** may be configured to contact the position-controlling member **890a** and cause the position-controlling member **890a** to rotate into the position in which the roller members **855** are disengaged from the flange

690b, thereby allowing the mold **600** to be removed by retraction of the pressure ram **200**.

In certain embodiments of the present invention, the position-controlling member **890a** and/or the mounting blocks **870** may be engaged with a limit switch (not shown) or another type of detection mechanism to determine when the position-controlling member **890a** has been rotated into the position in which the roller members **855** are disengaged from the flange **690b** and to stop the reverse rotation of the rotatable member **300** in response thereto. In some instances, the limit switch or other detection mechanism may also direct or actuate the offsetable member **400** to return to a home position such that the longitudinal axis **620** of the mold **600** realigns with the frame axis **150**. Accordingly, the state in which rotation of the rotatable member **300** has ceased, the roller members **855** are disengaged from the flange **690b**, and the offsetable member **400** has returned to the home position may be defined as a register state. In the register state, the pressure ram **200** may be actuated to retract from the mold **600**, thereby causing the mold-handling device **700** to begin the process of lifting the mold **600** from the bearing member **420** so as to allow the mold **600** to be removed from the mold well **500**.

FIGS. 14A and 14B show one embodiment of a mold angle sensing device **820**, wherein the sensors **830** are configured as contacting type sensors. Such a configuration of a mold angle sensing device **820** may be used in conjunction with any embodiments of the present invention, but is described herein with embodiments using a mold-handling device **700** as discussed in connection with **FIGS. 11A-11D**. The sensors **830** are normally biased toward the mold **600** by, for example, springs (not shown). In some instances, such as, for example, to perform apparatus testing calibration procedures, or the like, the pressure ram **200** may need to be lowered toward the bearing member **420** without the mold **600** in place within the mold well **500**. In those instances, the sensors **830** protruding into the mold well **500** may be at risk of damage due to contact with the ram head **230**. Accordingly, the mold angle sensing device **820** may also include a sensor guard **840** capable of moving and retaining the sensors **830** out of the path of the ram head **230**. As shown, the sensor guard **840** may be pivotably attached to the mold angle sensing device **820** and having a free end **845** movable between an inoperative position, away from the sensors **830**, as shown in **FIG. 14A**, and an operative position, as

shown in **FIG. 14B**, where the free end **845** engages the sensors **830** so as to recess the sensors **830** into the mold angle sensing device **820**. In the operative position, the free end **845** may be secured to the mold angle sensing device **820** so as to retain the sensors **830** out of the path of the ram head **230**.

Many modifications and other embodiments of the invention set forth herein will come to mind to one skilled in the art to which this invention pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. For example, the apparatus **10** may be configured to receive and manipulate the mold **600** in various orientations, such as "upside down" or horizontally, subject to the aforementioned requirements of the gyratory compaction process. More particularly, for instance, the apparatus **10** may be configured and oriented such that the pressure ram **200** exerts the necessary pressure from a lower end of the mold **600**. Accordingly, in such instances, the offsetable member **400** / rotatable member **300** assembly would be disposed toward the upper end of the mold **600** and, as such, one skilled in the art will appreciate that an appropriate securing device (not shown) for securing the mold **600** to the offsetable member **400** will be required along with an appropriate mold-handling device **700**. Other components of the apparatus **10** will also need to be appropriately configured. Therefore, it is to be understood that the invention is not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.